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Hecla Mining Company

ESCALANTE UNIT

March 1, 1990

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DIVISION OF
OIL, GAS & MINING

Wayne Hedberg
Natural Resources Department
Utah division of Oil, Gas & Mining
3 Triad Center, Suite 350
Salt Lake City, Utah 84180-1203

Dear Mr. Hedberg

Mac Croft requested information related to the permeability of the clay liner in the Escalante Tailings Impoundment. I have researched available information on file and came up with a report by FOX Consultants Inc. of Denver, CO. prepared in 1984, by James M. Johnson, P.E., Project Geotechnical Engineer and Steve G. Vick, P.E., Geotechnical Section Head. The following are excerpts from that report.

PURPOSE AND SCOPE

The purpose and scope of services provided by Fox Consultants Inc, during the field investigation include:

1. Drilling and sampling at one location within the tailings impoundment to provide a vertical profile of the tailings, compacted liner and natural foundation materials.

2. Conducting a laboratory testing program on the retrieved samples to measure moisture content, dry density, specific gravity and permeability.

3. Estimating the potential for seepage migration through the liner during (a) the original design life of the tailings pond and (b) a possible extended tailings pond life including an additional 10 to 15 feet of deposited tailings.[1]

[1] Stage IV 15 foot dam raise never completed

P.O. BOX 310 / ENTERPRISE, UTAH 84725 / (801) 439-5355

FIELD INVESTIGATION

The field investigation consisted of a single borehole drilled on June 25-26, 1984 through the tailings, protective soil cover, compacted liner and natural foundation soils to a total depth of 42.5 feet. The boring was drilled at the approximate location shown on Figure 1. The subsurface stratigraphy encountered is shown on the attached borehole log on Figure 2. ?

The borehole was advanced with 6 inch diameter hollow stem auger powered by a CME 55 drill rig. No water or drilling fluid was used, except for water used to actuate the hydraulic piston sampler. Continuous sampling was attempted in all of the soils encountered. The upper 17 feet of the tailings deposit was sampled using a hydraulically activated Gregory Undisturbed Piston Sampler fitted with 3 inch diameter Shelby tubes. Each sample was weighed and measured in the tube prior to sealing with soil seals and wax for transportation and storage. After the piston sampler met refusal at 17 feet a CME continuous sampler (which attaches to the lead auger section) was used to sample the rest of the tailings, the protective cover, the compacted liner, and the natural foundation soils to a depth of 42.5 feet. Sample recovery with the CME sampler was only fair due to lack of a vacuum at the top of the sample and plugging of the sampler shoe with gravel particles. The samples were retrieved in 2-1/4 inch diameter acrylic tubes which were weighed prior to sealing with plastic caps and duct tape.

The completed drill hole was backfilled with a cement-water grout mix from the bottom through the liner to a depth of 22 feet. A standpipe piezometer, consisting of 10 feet of hand-slotted, 1 inch diameter PVC pipe wrapped in filter cloth and 17 feet of unslotted pipe, was installed above the grout seal. Additional piezometer installation details are shown on the attached borehole log.

LABORATORY INVESTIGATION

The piston and hollow auger samples were transported to our soils laboratory in Wheat Ridge, Colorado for testing. Each tailings sample was tested for dry density, specific gravity and permeability. The permeability measurements were made on samples still inside of their plastic or steel sampling tubes. The samples were extruded and visually classified following permeability testing. The cover, liner and foundation soils were tested for moisture content and dry density. All samples were visually classified, and moisture contents were measured on a inch by inch basis where possible. The results of the laboratory investigation are tabulated in Table 1 and shown in Figures 3 and 4.

RESULTS OF INVESTIGATION

Stratigraphy

The subsurface stratigraphy encountered at the borehole is shown on the attached borehole log (Figure 2). the strata included 23.7 feet of tailings, 12 inches of protective cover, 20 inches of compacted liner and approximately 16 feet of natural foundations soils. No free water surface was encountered at any elevation within the borehole during drilling. A single, subsequent piezometer reading, made on July 17 1984, indicated free water at 21.8 feet, but this reading is not substantiated by drilling observations and cannot be confirmed.

The tailings samples consisted largely of silt with some layers of fine sand and occasional thin clayey seams. The measured dry density values ranged from 81.6 pcf to 89.2 pcf after eliminating the badly disturbed samples 9 and 10. Specific gravity measurements varied from 2.63 to 2.71, and the measured tailings permeability values ranged from 1.8×10^{-2} cm/sec to 6.3×10^{-6} cm/sec with a harmonic mean of 1.9×10^{-5} cm/sec.

Both the protective cover above the liner and natural foundation soils below it consisted of sand and gravel with varying amounts of silt and occasional calcareous layers. A thin clay seam was encountered from 24'3" to 24'5" depth in the protective cover.

The compacted liner sample consisted of clayey sand with a trace of gravel. The average dry density of the sample containing the liner was 99.9 pcf. However, this sample also contained 8 inches of protective cover and 2 inches of natural foundation soils as well as 20 inches of compacted liner.

Moisture and Saturation Profile

The moisture content profile of the materials removed from the borehole is shown on Figure 3. The corresponding profile of degree of saturation, computed from moisture content and average dry density values, is shown on Figure 4. In general the moisture contents decrease with increasing depth, being highest in the tailings, intermediate in the cover and compacted liner, and lowest in the foundation soils. As shown on Figure 3, measured moisture contents of the liner lie within the range of the original compaction moisture content. Also, moisture contents in the foundation are at or below values measured prior to impoundment construction.

In the overlying tailings, moisture contents varied from 24.6 to 33.2 percent with the exception of sample 10 which had been so badly disturbed during sampling that is appeared to have been reslurried. The moisture contents of samples 1 through 6 and 8 ranged from 24.6 to 31.8 percent, which corresponds to approximate saturation levels of 70 to 90 percent as indicated on Figure 4. The moisture content for sample 9 of 33.2 percent (16.85 to 19.2 feet) corresponds to approximately 100 percent saturation. It is unclear whether this is due to sample disturbance and contamination with water used to actuate the piston sampler, or whether this saturation value indicated proximity of the sample to a phreatic surface. In any case, the overall trend of the saturation data in the tailings is a tendency for decreasing saturation with depth. This trend is consistent with the unsaturated conditions in the underlying liner cover material.

The moisture contents of the protective cover material varied from 9.2 to 19.7 percent, which corresponds approximately to 40 to 80 percent saturation. These moisture contents are considerably higher than when the material was placed, making it likely that the cover was once saturated and then drained to the current moisture condition following activation of the underdrain system. Typical placement moisture contents are believed to have originally been between 5 and 10 percent.

The compacted liner moisture contents varied from 11.8 to 20.4 percent after eliminating thin samples which were dominated by gravel particles. These values correspond to approximately 50 to 85 percent saturation. As shown on Figure 3 the moisture contents lie within or slightly below the range of compaction moisture contents measured during liner placement in this portion of the pond. An obvious wetting front is difficult to discern on the basis of the data shown on Figure 3 and was not visually apparent during sample extrusion. Since the top 3 inches of the liner displayed slightly higher moisture contents than the material underlying it, the wetting front penetration has been estimated to be 3 inches at the most, if it is present within the liner as all.

The natural foundation moisture contents varied from 4.2 to 10.6 percent after eliminating thin samples which were dominated by gravel particles. These moisture values fall within the range of foundation moisture contents measured during the subsurface investigation conducted for design of the mill and tailings pond. The corresponding saturation levels range from 25 to 55 percent, confirming that the wetting front has not advanced into the foundation soils.

Best interpretation of the moisture and saturation data suggests that the entire tailings impoundment system is probably unsaturated, with the possible exception of perched saturation in the extreme lower portions of the tailings deposit. An unexpected result of the investigation is that the cover material is unsaturated. This would imply that the entire cover layer acts as a drainage layer in removing moisture from the tailings and conducting it to the central and lowest portion of the impoundment. This interpretation, which would be consistent with a very recent theoretical study (Reference 6), suggests that the comparatively high permeability of the cover material greatly magnifies the effectiveness of the slotted-pipe underdrains and plays a major role in keeping the compacted liner from experiencing any significant gravity pressure head.

UNSATURATED/SATURATED FLOW ANALYSIS

The maximum 3 inch wetting front penetration was input to the Green-Ampt equation coupled to a continuity equation (Reference 1) in an attempt to back calculate values of key input parameters. The back calculated parameters were then to be used as input for prediction of future wetting front penetration. The governing relationship is:

$$t = \frac{n_1 Q_1}{k_1} \left[L - \{Y - Y_{\bullet 1}\} \ln\left\{\frac{L + y - Y_{\bullet 1}}{Y - Y_{\bullet 1}}\right\}\right]$$

where: t = time required for wetting front to penetrate liner to depth L.

n_1 = porosity of compacted liner (0.353).

Q_{i1} = volumetric water content of liner at placement (0.254).

K_1 = saturated permeability of liner (5.7×10^{-7} cm/sec).

L = depth of wetting front penetration within liner.

Y = hydrostatic head at the top of the liner.

$Y_{\bullet 1}$ = suction head at wetting front within the liner.

The average hydrostatic head Y and the time of application t were estimated to be 10 feet and 14 months based on tailings pond operating records (Reference 5). for simplicity, it was assumed that activation of the underdrain system after the first 14 months of pond operation reduced the hydrostatic head to zero during the subsequent 21 months of operation. The suction head Y was estimated to be negative 950 cm based on c correlation obtained from Reference 2. The porosity and volumetric water content values were based on field measurements made during construction and during this investigation. The liner permeability was based on compacted samples previously tested in the laboratory.

The back calculated values of the key input parameters assuming 3 inches (7.5 cm) of wetting front penetration under 10 feet (305 cm) of hydrostatic head and negative 950 cm of suction head acting for 14 months are listed below:

$K = 6.1 \times 10^{-11}$ cm/sec.

$Y - Y_{s1} = 0$ (implies $Y_{s1} = Y = +305$ cm).

Back calculated permeability varies from measured values by four orders of magnitude, a difference too large to be explained by experimental error in the laboratory tests. Moreover, the back calculation of a positive suction pressure implies the presence of a reverse suction gradient and is physically unreasonable. The inability of the Green-Ampt equation (which FOX considers the best available theory) to produce reasonable agreement with observed conditions indicated that the theory is deficient in modeling this particular situation. Predictions of future wetting front penetration based on this theory, which are several orders of magnitude faster than observed in this investigation, are therefore believed to be limited use.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions obtained from this study are as follows:

1. Based on measured moisture contents of thin slice samples from the liner and foundation soils, the wetting front does not yet appear to have penetrated through the liner or into the foundation. The wetting front may have progressed 3 inches at most into the liner under approximately 10 feet of head which existed for approximately 14 months prior to activation of the underdrain system.

2. Theoretical predictions of the time required for the wetting front to penetrate 3 inches into the liner are several orders of magnitude faster than indicated by field observations. Therefore, theoretical estimates of the time required to penetrate the full depth of the liner are believed to be unreliable.

3. The underdrain system appears to have eliminated or significantly reduced the phreatic surface within the tailings deposit, which in turn greatly lowers the potential for seepage migration through the compacted liner. Unsaturated conditions within the 12 inch thick protective cover over the liner indicate that the cover material greatly enhances the effect of the underdrains in reducing fluid pressures acting on the liner. Therefore, even if the 3-inch liner wetting front location is indeed accurate, it would be incorrect to

extrapolate this wetting front velocity to future conditions because significant head probably will not act on the liner so long as the underdrain/cover system maintains its present effectiveness.

4. Although the vertical permeability of individual tailings samples varied from 1.8 x 10^{-2} cm/sec to 6.3 x 10^{-6} cm/sec, the average vertical permeability of the deposit is practically identical to the value of 1.85 x 10^{-5} cm/sec obtained for near-dam surface samples in an earlier limited investigation of tailings properties (Reference 4).

Based on the limited wetting front penetration of the liner observed in this study, the great depth to the local ground water table (approximately 390 feet), and the apparent effectiveness of the underdrain system in reducing the head on the liner, FOX feels that the potential for seepage migration through the liner foundation to the ground water table during and following the design life of the impoundment is extremely small.

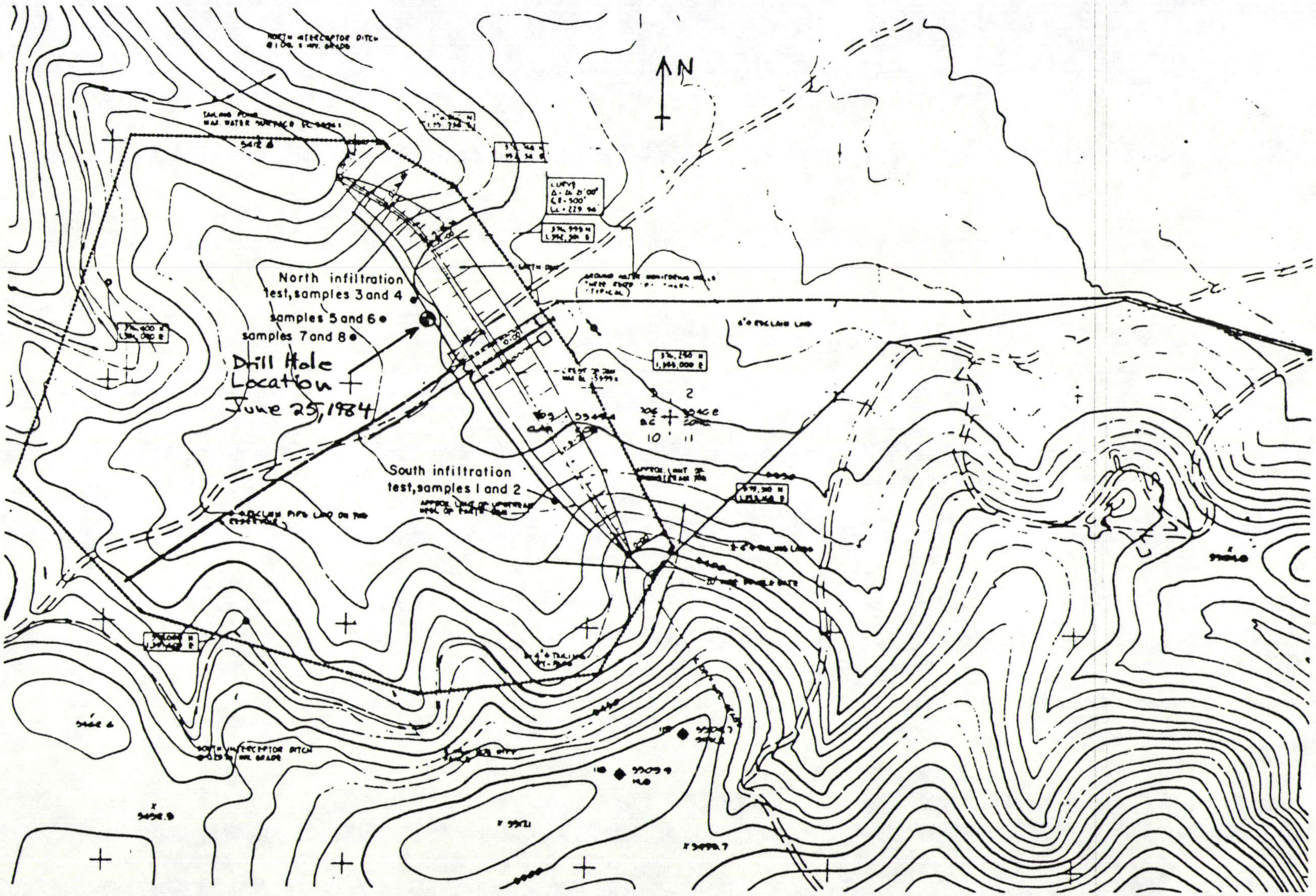
not true! (only under dewatered mine conditions)

If you have any questions concerning this report, please feel free to call.

Sincerely,

Brent Willoughby

Brent Willoughby
Unit Manager



ESCALANTE SILVER MINE – SITE PLAN OF STAGE III
TAILINGS POND AND DAM

FOX CONSULTANTS
SUBSURFACE EXPLORATION LOG

SHEET 1 OF 1

PROJECT Ranchers Escalante PROJECT NO. 01-1278 BORING NO. 1

ELEVATION 5375' TOTAL DEPTH 42.5'

DATE BEGUN June 25, 1984 DATE FINISHED June 26, 1984 LOGGED BY J. Johnson REVIEWED BY P. Gregory

TYPE AND SIZE OF HOLE	DEPTH (feet)	GRAPHIC LOG	LITHOLOGY AND PHYSICAL CONDITION	PENETRATION RESISTANCE	R Q D (%)	CORE RECOVERY (%)	SAMPLE LOCATION	UNIFIED SOIL CLASSIFICATION	MOISTURE CONTENT	% PASSING 200	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	DRY DENSITY (pcf)	PIEZOMETER INSTALLATION DETAILS
HA; Shelby Tube Piston Sampler	0–23		SILT - Some sand, trace clay - gray - moist - little or no plasticity - alternating layers of fine to coarse silt or fine sand with occasional bands of clayey material TAILINGS			NR (approx. 16–17 ft); NR (approx. 20–22 ft)		ML						tailings cuttings; 1" φPVC pipe wrapped with filter cloth
HAC	23–24		GRAVEL-Some sand and silt-brown-moist	32ft				GM-SM						cement grouted hole
	24–26		SAND - Clayey with some gravel - tan - moist to dry - hard - plastic					SC-CL						
2" Diameter CME Continuous Sampler	26–42.5		GRAVEL AND SAND - well-graded - medium dense - fairly dry			NR (approx. 30–33 ft); NR (approx. 34–42.5 ft)		GP-SP						
	42.5'		End of Hole											

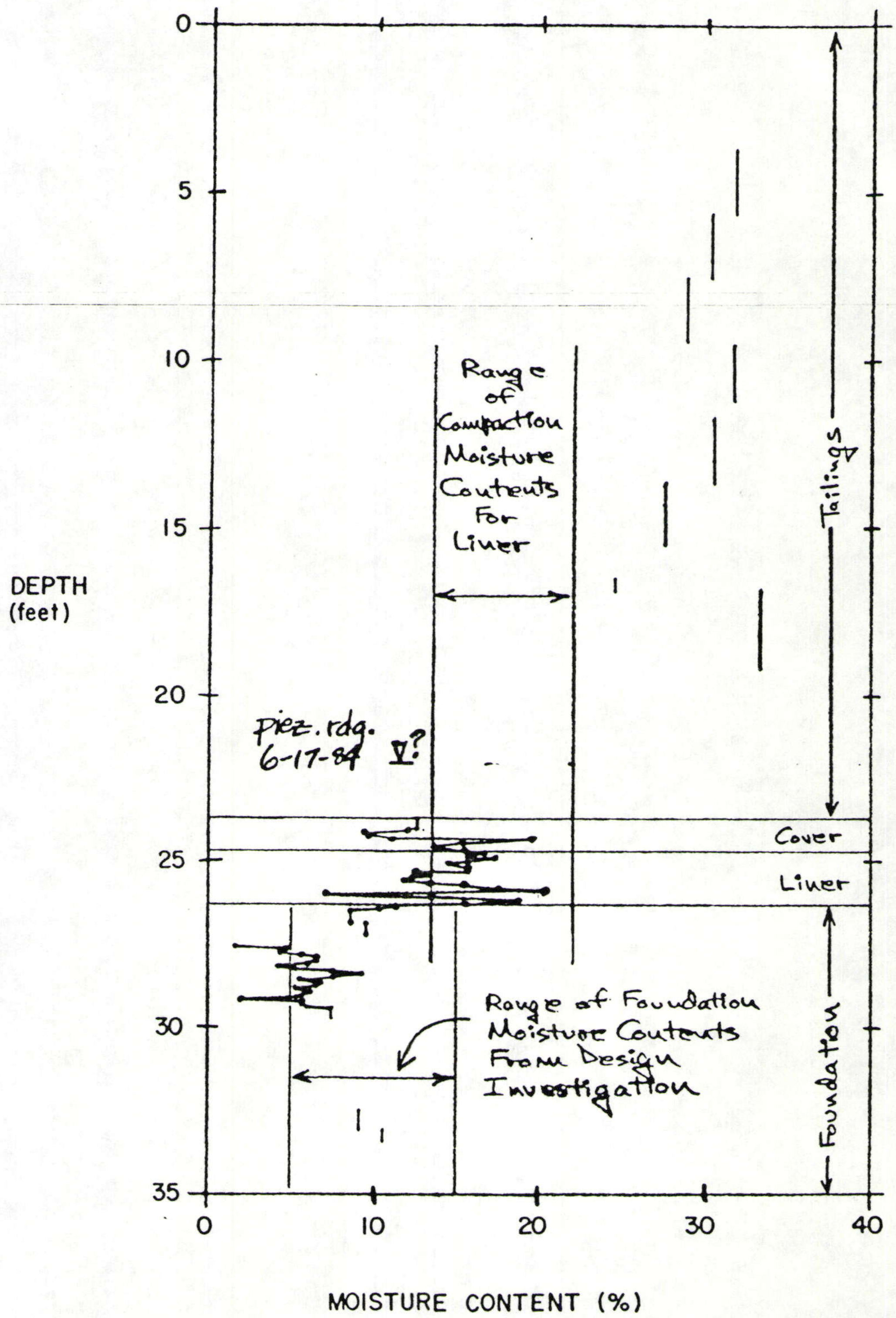
Depth scale: 5, 10, 15, 20, 25, 30, 35, 40, 45

HOLE TYPES
SA - SOLID AUGER
HA - HOLLOW AUGER
C - CORE HOLE
R - ROTARY HOLE
HAC - HOLLOW AUGER WITH CONTINUOUS SAMPLER

EXPLANATION
CORE RECOVERY
CORE LOSS
LOCATION OF SAMPLE ANALYZED IN LABORATORY
LOCATION OF SAMPLE NOT ANALYZED IN LABORATORY

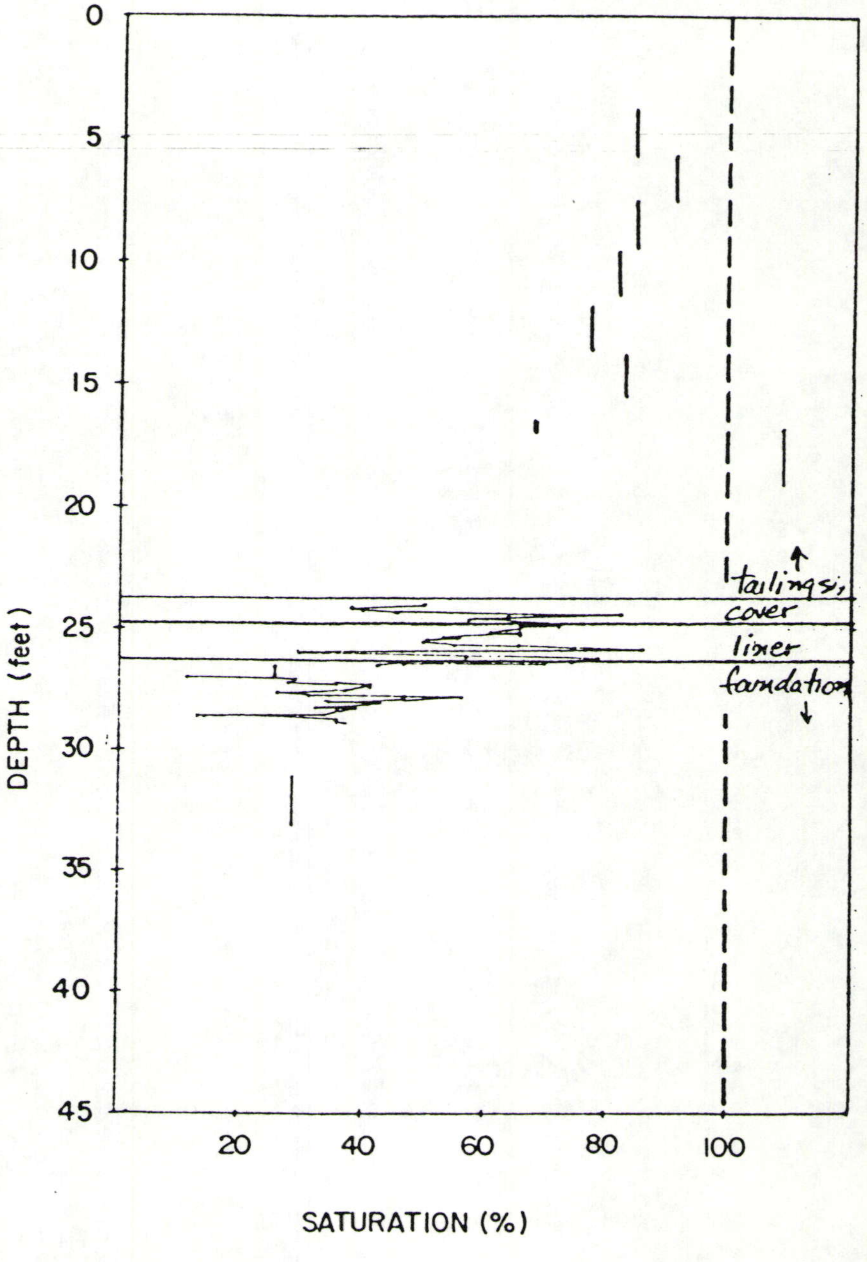
STANDARD PENETRATION TEST
RECORDED AS NUMBER OF BLOWS WITH A 140 POUND HAMMER FALLING 30 INCHES. REQUIRED TO DRIVE A STANDARD SAMPLER ____ INCHES

• USED 2.5" DIAMETER CALIFORNIA SAMPLER



MOISTURE CONTENT PROFILE — DRILL HOLE NO. I
ESCALANTE SILVER MINE — ENTERPRISE, UTAH

Figure 3



SATURATION PROFILE

TABLE 1

LABORATORY TEST RESULTS - TAILINGS POND DRILL HOLE

SAMPLE NO.	SAMPLE DEPTH (feet)	SAMPLE DESCRIPTION	MOISTURE CONTENT* (%)	AVERAGE MOISTURE CONTENT* (%)	AVERAGE DRY DENSITY (pcf)	SPECIFIC GRAVITY	PERMEABILITY (cm/sec)
1(ST)	3.7 - 5.6	Banded silt, some sand (tailings)		31.8	83.4	2.68	1.4×10^{-5}
2(ST)	5.6 - 7.5	Banded silt, some sand (tailings)	—	30.2	89.2		3.0×10^{-5}
3(ST)	7.5 - 9.4	Banded silt, some sand (tailings)	—	28.8	87.7	2.71	1.7×10^{-5}
4(ST)	9.5 - 11.3	Banded silt, some sand (tailings)	—	31.7	82.4		6.3×10^{-6}
5(ST)	11.7 - 13.6	Banded silt, some sand (tailings)	—	30.4	81.6	2.63	1.8×10^{-2}
6(ST)	13.6 - 15.5	Banded silt, some sand (tailings)	—	27.6	88.6		1.1×10^{-4}
7(ST)	15.5 - 15.6	No push, no recovery	—			—	
8(ST)	16.5 - 16.85	Banded silt, some sand (tailings)	—	24.6	—	—	—
9(CS)	16.85 - 19.2	Banded silt, some sand (tailings)	—	33.2*	92.5	2.69	6.8×10^{-5}
10(CS)	21.9 - 23.7	Banded silt, some sand (tailings)	—	50.0**	98.4	—	1.1×10^{-4}
11(CS)	23.7 - 24.0	Sand, some gravel and silt (cover)	—	12.6	—	—	—
12(CS)	24'0" - 24'1"	Sand, some gravel and silt (cover)	12.0				
	24'1" - 24'2"		9.2				
	24'2" - 24'3"		9.5				
	24'3" - 24'4"	Clay, sandy, some silt (cover)	11.0				
	24'4" - 24'5"		19.7				
	24'5" - 24'6"	Silt and sand, trace clay (cover)	15.3				
	24'6" - 24'7"		13.7				
	24'7" - 24'8"		15.5	14.3	99.9		
	24'8" - 24'9"	Sand, clayey some silt and gravel	16.8				
	24'9" - 24'10"		15.8				
	24'10" - 24'11"	to	17.3				
	24'11" - 25'0"	Clay, sandy, some silt and gravel	15.8				
	25'0" - 25'1"	(liner)	14.5				
	25'1" - 25'2"		15.8				
	25'2" - 25'3"		15.8				
	25'3" - 25'4"		12.6				
	25'4" - 25'5"		13.3				
	25'5" - 25'6"		12.2				
	25'6" - 25'7"		11.8				
	25'7" - 25'8"		13.3				
	25'8" - 25'9"		15.7				
	25'9" - 25'10"		17.9				
	25'10" - 25'11"		20.4				
	25'11" - 26'0"		7.0 (rock)				
	26'0" - 26'1"		13.6				
	26'1" - 26'2"		18.8				
	26'2" - 26'3"		17.3				
	26'3" - 26'4"		15.6				
	26'4" - 26'5"		11.1				
	26'5" - 26'6"	Silt, sand and gravel, trace clay (foundation)	10.2				
13(CS)	26.5' - 26.9'	Sand, silty, some gravel	—	8.6	87.4	—	—
14(CS)	26.9' - 27.2'	Sand, gravelly, trace silt	—	9.6	—	—	—
15(CS)	27.6" - 27'7"	Sand, gravelly, trace silt (foundation)	1.8 (rock)				
	27'7" - 27'8"		4.6				
	27'8" - 27'9"		4.5				
	27'9" - 27'10"		5.8				
	27'10" - 27'11"		6.6	5.7	115.6	—	—
	27'11" - 28'0"		6.6				
	28'0" - 28'1"		6.0				
	28'1" - 28'2"		4.2				
	28'2" - 28'3"		5.1				
	28'3" - 28'4"		7.4				
	28'4" - 28'5"		9.1				
	28'5" - 28'6"		7.6				
	28'6" - 28'7"		5.5				
	28'7" - 28'8"		6.9				
	28'8" - 28'9"		6.7				
	28'9" - 28'10"		5.2				
	28'10" - 28'11"		6.3				
	28'11" - 29'0"		5.8				
	29'0" - 29'1"		5.4				
	29'1" - 29'2"		2.0 (rock)				
	29'2" - 29'3"		5.8				
	29'3" - 29'4"		5.8				
	29'4" - 29'5"		6.0				
16(CS)	29.4' - 29.7'		—	7.4			
17(CS)	32.5' - 33.1'		—	9.1	89.2	—	—
17(CS)	33.1' - 33.4'		—	10.6	—	—	—

KEY: ST = Shelby Tube
CS = Continuous Sampler

*Moisture contents of slices approximately 1" thick.
**Sample appears disturbed.

REFERENCES

[1] Bureau, Gilles, "Design of Impervious Clay Liners by Unsaturated Flow Principles," Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado, Oct. 26-27, 1981, pp. 647-664.

[2] McWhorter, D. B. and J. D. Nelson, "Drainage of Earthen Lined Tailings Impoundments," Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado, Nov. 20-21, 1978, pp. 31-49.

[3] Fox Consultants, Inc., Investigation of Tailings Properties and Evaluation of Underdrain System Performance for the Tailings Impoundment at the Escalante Silver Mine," prepared for Ranchers Exploration and Development Corp., Project No. 11114.0.

[4] F. M. Fox & Associates, May 14, 1980, Geotechnical Investigation for the Proposed Mill and Tailings Disposal Areas, Escalante Project," prepared for Ranchers Exploration and Development Corp., Project No. 1-2762-3106.

[5] Scheffel, Randy, personal correspondence, July 17, 1984.

[6] Cosler, D. and R. Snow, "Leachate Collection System Performance Analysis," Journal of Geotechnical Engineering, ASCE, August, 1984.